MULTIPLE-BEAM MICROWAVE TUBES

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ABSTRACT

ISTOK has been developing multiple-beam microwave tubes for the last 35 years and have produced a wide range of microwave and millimeter wave devices which are unique to ISTOK. Multiple-beam klystrons, TWT's, and BWO's provide low operating voltages, high power, low noise, and the possibility of larger operating bandwidth. The devices discussed include mbk's, pulsed multimode multiple-beam TWT's, and multiple-beam BWO's operating at wavelengths as short as 0.2 mm.

INTRODUCTION

The progress of science and technology has continuously posed new challenges for the designers of microwave tubes. Specific problems include reduction of operating voltages, minimizing weight and dimensions of the tubes and their power supplies, increasing the bandwidth of amplifier klystrons, developing TWT-based multimode amplifiers, and developing effective broadband tunable oscillators for mm- and sub-mm wavelength bands. One of the unique engineering solutions to effectively solve these and other problems is the use of multiple-beam designs of microwave tubes.

Multiple-beam tubes (klystrons, TWTs, and BWOs) use several electron beams, and each beam propagates along its own individual transit-time path through a slow-wave structure or a resonator unit. The current and perveance of each separate beam are not high, but the total current and perveance of the entire multibeam stream can be high. As a result of use of the high-perveance multibeam stream, the operating voltage is significantly reduced (2 to 10 times) with a consequent reduction in dimensions and weight of the devices and their power supplies. At the same time individual low-perveance beams are better focused and bunched, and give up their energies to the field of the slow-wave structures and resonators in an efficient manner; thus, excellent performance may be attained.

The multiple-beam concept for microwave tubes has been proposed by a number of authors even at the early stages of advancement of microwave electronics [1,2]. Multiple-beam klystrons, in particular, were studied in the USA in the 50's and 60's [3]. However, as these publications have shown, this work did not receive wide recognition and did not result in the emergence of the production prototypes. For a long period of time, over 35 years, RPC ISTOK has been conducting research and development for a wide range of multiple-beam microwave tubes. These studies have resulted in realization of four original families of multiple-beam tubes. Following sections contain a brief presentation of these devices.

HIGH-POWER MULTIPLE-BEAM KLYSTRONS

Significant amount of R&D at RPC ISTOK has been devoted to the multiple-beam klystron (MBK) operating on the fundamental resonator mode [4]. Typical construction of such a klystron is given as Figure 1. The

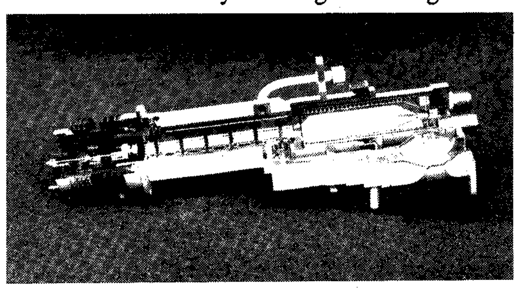

Figure 1. MBK Cross-Section.

distinctive feature of this design is the use of several isolated metal channels which are the drift channels for the electron beams. The number of channels is influenced by achieving maximum number of channels in a minimum cross-sectional area, and is usually chosen as 7, 19, 37, and so forth.

As the number of beams in the MBK grows, the bandwidth increases, the operating voltage decreases (due to high total beam perveance), and the required magnet becomes smaller. Examples of such relationships are given in Figure 2.

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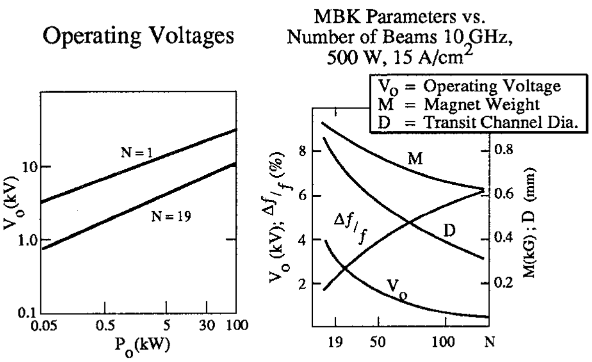

Figure 2. Predicted MBK Parameters.

During MBK development, a number of new engineering solutions were required. Some such areas include electron guns, which form a multibeam electron stream with a near-laminar structure of beams; total perveance of the guns is from 3-10 $mA/V^{3/2}$; the guns include an isolated electrode (grid) to focus and control the beams. Magnetic focusing systems were another challenging area for MBK designs. Beam transmission of over 99% for CW tubes and 96% for pulsed tubes requires a low level of the transverse component of the magnetic field and values of $B_1/B_n \leq 0.01$-0.02 have been achieved. In many cases the low voltage and short length of the drift channels have permitted a reduction of weight of the magnets (and of the MBK) by an order of magnitude when compared to comparable single-beam klystrons.

The studies performed have resulted in the advent of the MBK family with a wide range of parameters for various frequency bands. Some of these tubes are described in Table 1.

Table 1. Multiple Beam Klystron Parameter Ranges

Parameters	Band		
	X	S	L
Output Power (kw)	25 - 50	1 - 1000	5 - 10
Duty (%)	20 - 10	50 - 2	cw
Bandwidth (%)	2.5 - 6	5 - 10	15 - 20
Voltage (kV)	12 - 15	2 - 35	5 - 7
Efficiency (%)	25 - 35	35 - 50	40
Gain (dB)	40	40	40
Weight (kg)	7.5 - 14	7 - 20*	20*

* Without Magnet

MBK's having pulsed power of tens of kW's and 6%-bandwidth have been produced at the upper end of the microwave frequencies; this performance is comparable to that of coupled-cavity TWT's. The MBK voltage is 2 to 3 times lower than similar single-beam klystrons.

HIGH-POWER MULTIPLE-BEAM TWT's AND RELATED AMPLIFYING CHAINS

Success of the MBK suggested use of the advantages and developed technology of the MBK tubes to develop low-voltage multiple-beam multimode TWT amplifiers [5]. One such amplifier has been developed as a chain of two TWTs. The first stage is a single-beam multisection TWT having high gain, used as a preamplifier, and the second stage is a single-section, "see-through" TWT designed for a propagating signal. A multiple-beam coupled cavity TWT was used as the output amplifier.

The multiple-beam TWT is packaged with a permanent magnet (as with MBK) due to its short length. As a result it has been possible to provide good propagation of the signal to the collector and consequently to significantly improve the TWT parameters. Both tubes of the chain have the same low operating voltage, permitting operation from a common power supply. The low operating voltage of multiple-beam tubes permits this simplification.

A cut away cross-section view of a multiple-beam TWT is shown as Figure 3. This tube uses a 36-beam electron-optical system. One of the coupled cavities of such a tube is shown as Figure 4. Since the coupled cavity is a slow-wave structure, it includes additional low-Q resonators to prevent self-oscillation.

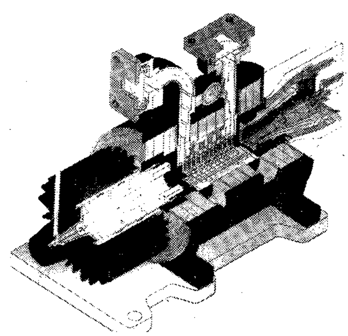

Figure 3. Cross Sectional View Of A High-Power Multiple Beam Dual-Mode TWT.

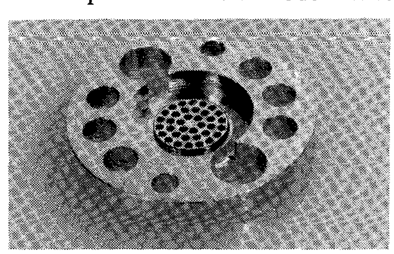

Figure 4. Element Of The Multiple-Beam TWT Slow-Wave Structure.

The "see-through" high perveance multiple-beam TWT has more effective mechanism of interaction, and as a result the multiple-beam TWT efficiency is 1.5 times higher than that of a comparable single-beam TWT. The most important advantage of the amplifying chain is its ability to provide multimode operation of the transmitter without additional tuning of voltage and output power.

MULTIPLE-BEAM BWO's

A number of important types of systems (for radars, instrumentation, and medicine) require broadband tunable oscillators. Parameters of these oscillators must meet stringent requirements, i.e., low voltages, electrical tuning of frequency, low weight and dimensions, operation at millimeter and sub-millimeter frequencies, good spectral characteristics, and must be capable of operation at high radiation levels and extreme temperatures. Semiconductor devices do not always meet such requirements.

RPC ISTOK has developed a series of multiple-beam low-voltage broadband tunable backward wave oscillators which satisfy the above-mentioned requirements. These BWO's have covered frequency ranges with the ratio of extreme frequencies of 3000:1. The highest frequency tube operates at 0.2 mm. Such tubes use a unique approach which consists of a multirow (multiple-beam) slow-wave, "interdigital" structure, and ribbon electron beams, 3 to 9 in number. The high total perveance of the beams permits low-voltage operation.

Non-convergent beams are used in the gun region, and this necessitated development of cathodes with current density up to 100's of A/cm^2. The slow-wave structures are manufactured using EDM techniques on a complete assembly to provide ideal alignment of the channels.

Electrostatic Focused Multiple-Beam BWO's

The main challenge in creating such BWO's has been the selection of the design approach and operating parameters such that effective interaction of the electron beam with the field and good focusing are achieved simultaneously over a wide range of operating voltages. Such a compromise has appeared possible due to the use of the original multirow slow-wave interdigital structure with isolated parts of the slow-wave structure.

Since 1959 the BWO with periodic electrostatic focusing has been protected by the author's certificate[6]; later it was patented in England, USA, Italy and France.

The developments thus implemented have resulted in the production of a series of multiple-beam low-voltage BWO's covering the frequency band from 1 to 40 GHz. Representative parameters of the multiple-beam miniature low-voltage (microperveance is from 10 to 30) BWO's are given in Table 2.

Table 2. Miniature Low-Voltage BWO Parameters

No	Band (GHz)	Min. Output Power mW	Max Voltage V	Current mA	Noise F^1=30 MHz dB/Hz
1.	2.5-3.64	12	150	60	-160
2.	9-12	10	300	60	-160
3.	8.15-12.4	12	350	60	-160

The devices are extremely stable and demonstrate useful lives in excess of 5000 hours.

The multiple-beam BWO's have found wide applications in radar equipment, radionavigation, radioaltimetry, and instrumentation.

Millimeter and Sub-Millimeter BWO's

Multiple-beam BWO's have been an important tool for mastering mm and sub-mm bands at RPC ISTOK. The BWO's for millimeter wavelengths use magnetic focusing of the beam. The basic structural implementation of the multirow (multiple-beam) interdigital system is covered by the author's certificate on this system received by ISTOK in 1956 [7]; it was subsequently patented in England, Germany and France.

The multiple-beam slow-wave structure has been produced as a complete unit using electrical discharge machining techniques; the pitch of the system is from 20 to 150 um. These tubes have used a planar 3-electrode gun with non-convergent optics. Longitudinal dimension of the gun is 3 mm; the gun has been placed into the magnetic field.

Miniaturized magnet-packaged mm-wave BWOs covering the entire mm-band have used small samarium-cobalt magnets, which have provided the field up to 400...600 mT in the operating gap of 22 mm.

In the course of development of the multiple-beam mm-wave BWO's, a number of engineering developments were necessary for successful operation. The development of the broad-band output coupler was particularly challenging involving material selection, development of matching devices and absorbers, and implementation of techniques to reduce parasitic oscillations.

A family of low-voltage multiple-beam broadband tunable BWOs covering the frequency range from 36 to 1500 GHz was developed. Parameters of the multiple-beam BWOs are given in Table 3. The multiple-beam BWO's for mm and sub-mm bands have been widely used in instrumentation, receiving systems, spectrometry, and biological research.

Table 3. Millimeter-Beam BWO Characteristics							
Parameter	**Packetized**						**Unpacketized**
Band, GHz	36-55	52-79	78.2-119	129.3-142.9	118-178	177-260	179-1500*
Output Power (min), mW	15-40	12-30	6-30	20-30	6-20	5-15	10-0.5
Voltage, kV	0.4-1.2	1.0-1.2	0.5-1.5	1.1-1.5	0.5-1.5	0.7-2	1.0-6.0
Current, mA	20-25	20-25	20-25	20-25	20-25	20-25	25-45
Weight, kg	1	1	1	1	1	1.5	1.5
Min. Life, hours	2000	2000	1000	1000	1000	1000	
Magnetic Field, Gauss							6000-11000

* 9 devices

CONCLUSION

These studies have shown that the use of the multiple-beam designs provide a powerful means for improving parameters of microwave tubes.

Production of the multiple-beam tubes has been possible as a result of use of the original engineering approaches in each of four above-cited device families.

Principal constructional solutions for the multiple-beam tubes have respective author's certificates.

The multiple-beam tubes, developed at RPC ISTOK, can be considered as an effective new generation of microwave tubes.

These microwave tubes have found a wide range of applications in various fields of science and technology in Russia.

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